Abstract

The basic questions addressed in this paper are how to avoid future surprise growth in Mission Operations and Data Analysis (MO&DA) costs, and how to minimize total MO&DA costs for planetary missions. The context of this paper and its accompanying conclusions is in the arena of JPL mission operations support. The fundamental conclusion is that there is no simple, single solution: the entire Project life cycle must be addressed. This is not a new message. It has been part of the results of each of the NASA-oriented MO&DA cost studies which have occurred over the last many years.

This paper provides a series of specific conclusions as determined from two studies aimed at breaking the historical mold. Several require changing the interface between NASA Headquarters and JPL management. Also identified are developments of better tools to aid in estimating and controlling MO&DA costs.

This paper will (1) provide a general background of MO&DA at JPL; (2) illustrate the conclusions via examples drawn from JPL missions, and (3) discuss the outcome tasks are they are currently being effected.

Background - Setting the Stage

The basic questions addressed here are how to avoid future surprise growth in MO&DA costs, and how to minimize total MO&DA costs for planetary missions. The fundamental conclusion is that there is no simple, single solution: the entire Project life cycle must be addressed. Either a shared NASA Headquarters, JPL, and Science Community management discipline is found for balancing the Flight and Ground Development process and for controlling mission design and science appetite; or else NASA must expect late surprises to be the norm, requiring greater reserves in early MO&DA plans.

This is not a new message. It has been part of the results of each of the MO&DA cost studies which have occurred over the last many years. NASA has been living in an environment that has consistently forced reduced and stretched development budgets where tough choices had to be made. These choices invariably included the delay of Ground System detailed definition and development with respect to the Flight System. The lack of early detailed definition of the Ground System and Operations leaves Operations ill-equipped to defend or even properly identify Flight-Ground trades and rather naturally leads to late surprises.

Furthermore, even the most efficient MO&DA system can not ameliorate the costs associated with designs of poor operability for extremely complex missions. JPL is addressing the relative contributions to the costs of the MO&DA, viz. (from high to lower) science requirements, mission requirements, spacecraft operability, and ground system operability.

In interviews with the Mission Operations Managers of all active planetary missions, a common theme was one of the value of today's (development) dollar versus tomorrow's (MO&DA) dollar. This time value of funding was recognized as a fact of life and provided the basis for increases in MO&DA cost during the project life cycle.

This paper provides a series of specific actions aimed at breaking the historical mold. Also identified are some in-process and recommended developments of better tools to aid in estimating and controlling MO&DA costs.

At this point it is important to pause and make an important point. There is a need important enough that it should not get lost ... increased funding is needed for continuous improvement plus advanced definition and development in MO&DA tools and systems to address support for future missions. For without continuos improvement efforts and this advanced work, JPL will be doomed to continue business as usual.

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Essentially the studies were directed toward addressing two primary needs:

(1) Eliminate surprises between NASA and JPL Flight projects with respect to MO&DA costs and mission content changes. This immediately leads to the need for better estimation of Mission Operations and Data Analysis (MO&DA) costs and the accompanying better management within these estimates. Included are the issues associated with management of mission content change.

(2) Minimize Ground System development and MO&DA costs by proper attention to design, implementation, operations, and controlled changes to the complete life cycle. These changes by their nature include modifications to the equivalent JPL/NASA processes and organizations.

Summary of Conclusions

The following section documents the most cogent conclusions reached by the studies.

(1) There has been significant growth in the last several years in NASA's MO&DA budget. In some parts of NASA, the MO&DA budget is approaching 25% of the total program. There are three principal reasons for this growth:

(i) the bow-wave affect of the post-Challenger deferral of launches and mission operations,

(ii) the increased complexity of mission objectives and increased lifetimes of the recent suite of NASA missions, and

(iii) a lack of attention to MO&DA cost estimation and containment.

(2) Cost models are needed that can predict both MO&DA cost as well as Ground System development costs. The application of these models, based on historical data, would have possibly enabled designers to better understand and address the issues associated with mission complexity, duration, magnitude, etc. when estimating MO&DA costs.

(3) Although a meaningful figure of merit to aid in comparative evaluation of projects costs remained elusive, the study efforts did gather some cost data for a significant set of GSFC and JPL missions which allows some modest conclusions.

Figure 1[*] shows the first year MO&DA budget (normalized to a full year) plotted against the total of ground and flight systems developments.[**]

At first glance, Figure 1 may appear be to just random scatter. When a range of percentage lines, 3.7% and 8%[***] are added to Figure 1, a useful pattern emerges: the vast majority of missions fall in this 3.7% to 8% band. It is easy to explain at least some of the outliers such as IRAS, which does not include the British and Dutch covered costs or LANDSAT which does not include the NOAA covered part of operations costs. The reasons for being high or low within the band are probably explainable by the detailed differences between projects. For example, TOPEX and Magellan (MGL) both have unique, very extensive data processing tasks as a part of the primary mission while COBE, Galileo, and Cassini had deferred those costs to after the first year. Additionally, even Hubble Space Telescope (HST), which is not shown to enable better presentation, falls within the range (3.8%) if refurbishment is subtracted from the MO&DA budget. Thus, a rule of thumb may be derived: 3.7% to 8% of total Project development cost is a reasonable value of first year prime mission MO&DA costs.

(4) Another area of interest was the importance of committing development phase funds in order to reduce MO&DA phase costs. Earlier definition of the ground/operations system and designing the ground system in concert with, instead of in response to, the flight system design would allow early definition, and thereby enable potential reduction in the MO&DA phase costs. Early and continued containment of science appetite, and the resulting mission and flight system complexity, is the most significant way to contain/control ground

[*] R. Miller of the MO&DA Study team researched and developed the costing data and comparisons for the team.

[**] For all the data for this section, the non-tracking-associated project support costs have been added the GSFC project costs. This adjustment was done to make a clearer comparison to the JPL numbers which always include the entire ground system development and operations budgets except for the Deep Space Network (DSN)

[***] First Year Operations Cost as a percentage of Total Project Development Cost.

system and MO&DA costs. Unfortunately NASA has been living in a funding environment that consistently forces reduced and stretched development schedules and the associated, inevitable delay of ground/operations system development.

This delay ill equips the ground system to defend or even properly identify Flight-Ground trades early enough to effect the flight system implementation. Also complexity/scope decisions are made without the ability to make ground system and MO&DA impact assessments. This last point is the major contributor to late identification of MO&DA cost "surprises".

Figure 2 shows the ground/operations system development costs as a function of total Project development costs. For missions with development costs less than $400M there seems to be relatively closely clustered costs within an area while missions above that clustered costing have a non-linear cost growth. The figure illustrates this relationship with a 3rd order polynomial least squared fit to the data that has a .99 correlation. This fit includes HST, which is not shown for plotting reasons. LANDSAT again appears to be a unique case and was not included in the fit. A first, sensible interpretation of this data is that there is a relatively fixed ground system cost for lower cost missions. The next observation is as mission cost grows so does mission complexity then follows operations cost. The resulting flight system complexity causes a greater than linear growth in ground/operations system complexity and resulting cost.

(5) Simply stated there is "no silver bullet" for control of MO&DA costs. Identification, containment and control of MO&DA costs must start in the project definition stage and carry through the project life cycle. This implies a concurrent engineering process* for the Flight and Ground Systems beginning with project definition. Along with this concurrency is a need for recognition of "proportionality" of the Ground System and the Flight System development resources. The balance of resources should be sustained at all times in the definition and development phase.

The early, continued involvement of Ground System Engineers to define and document the Operations Concepts will provide a basis for trades among mission requirements, science requirements and flight system operability. For certain this involvement should occur prior to the Project Definition Cost Review. These trades will enable earlier, better cost estimations for Ground System development and operations (MO&DA). These operability and operations concepts should be reviewed during each phase of the life-cycle (viz. Project Definition Cost Review (PDCR), PDR, and CDR). Finally, this dictates the need for a more formalized approach to spacecraft operability requirements analysis to enable MO&DA cost to be a parameter of Ground and Flight trade studies.

(6) Novel ideas with respect to handling MO&DA costs and reserve were investigated. Foremost among these was establishing post-launch MO&DA cost allocations (beginning in the pre-project phase). This cost allocation and its associated reserves will be refined during the life-cycle depending on the maturity of operations concepts and design. Separation of allocation and reserves between the flight and operations systems managers would help to establish a "level playing field" for dealing with issues related to flight and ground system operability. Then, the MOS Manager could potentially spend these reserves in at least two ways: (1) to fund Flight System operability improvements, and (2) to pay for Ground System impact of not making the Flight System changes.

(7) The Announcement of Opportunity (AO) process should be modified to have a two step acceptance process: a definition phase and a confirm-for-flight phase. The second step, accomplished a couple of years after initial selection, will enable a total life cycle impact analysis in light of a better understanding of the mission, science requirements, instrument operability, etc.

(8) In order to better recognize changes and control costs in general, a modified funding line item break down is recommended to distinguish between development costs (pre launch and post launch) and MO&DA costs. As shown in Figure 3, are identified four line items.

- Flight System development. This line item includes all Flight System development required for launch.
- Flight software development. This line item enables delayed flight software development for missions that have long cruise times .

* Concurrent Engineering refers to the process by which all disciplines/functions participate throughout the Life Cycle. This enables all the issues to be addressed from an integrated point-of-view.

- Ground System development. This line item again reflects the reality of delayed Ground System developments. Having a separate and accountable line item will provide a visibility mechanism for cost management. Additionally, this provides a recognition that development may continue until End-Of-Mission (e.g. Voyager).

- MO&DA. This line item is only for the operations activities and does not include development tasks as has occurred on past projects.

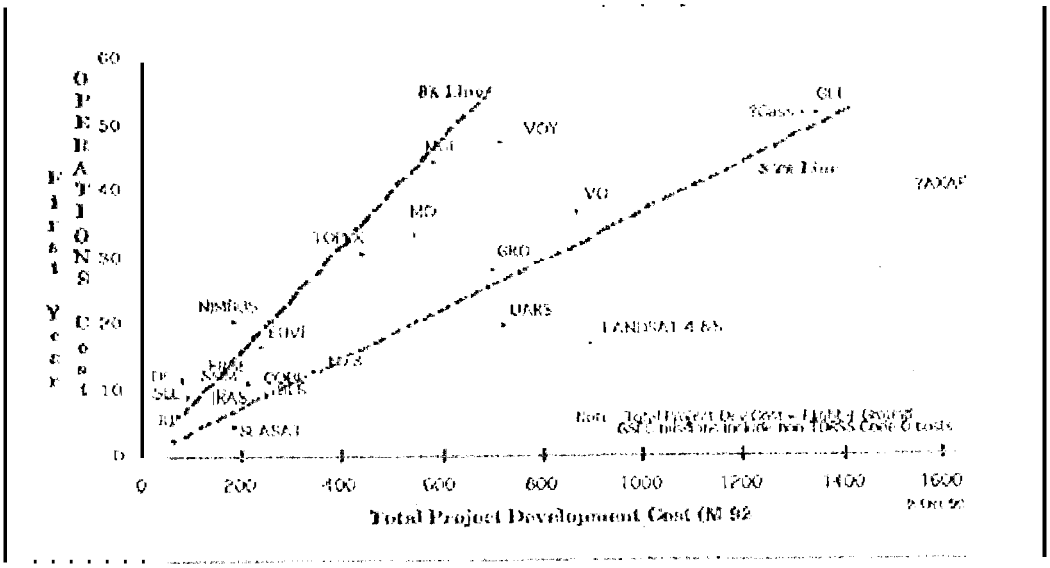

Figure 1 - First Year Operations Cost versus Total Project Development Cost

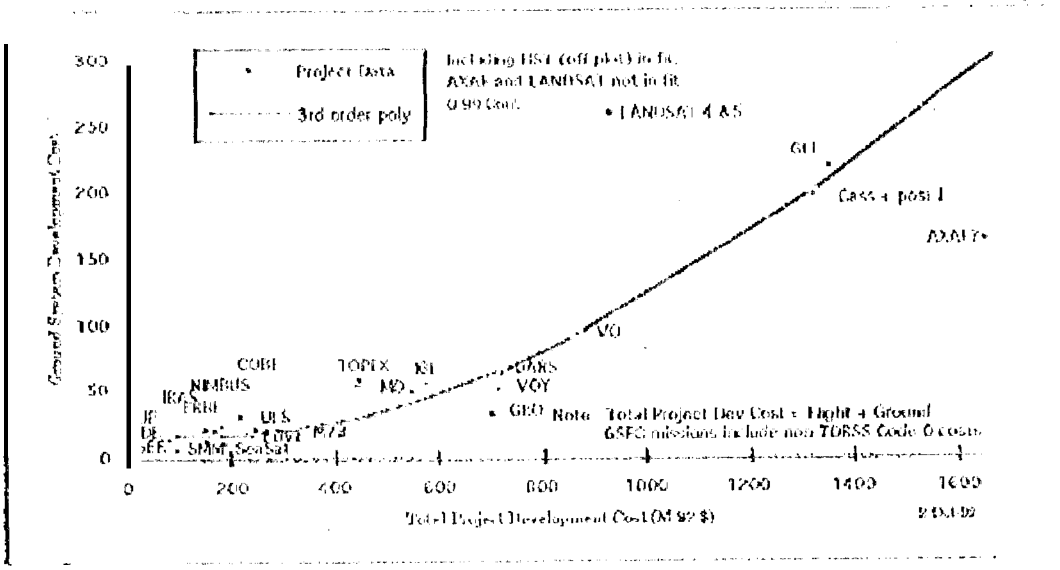

Figure 2 - Ground System Development Cost (M 92$) Versus Total Project Cost

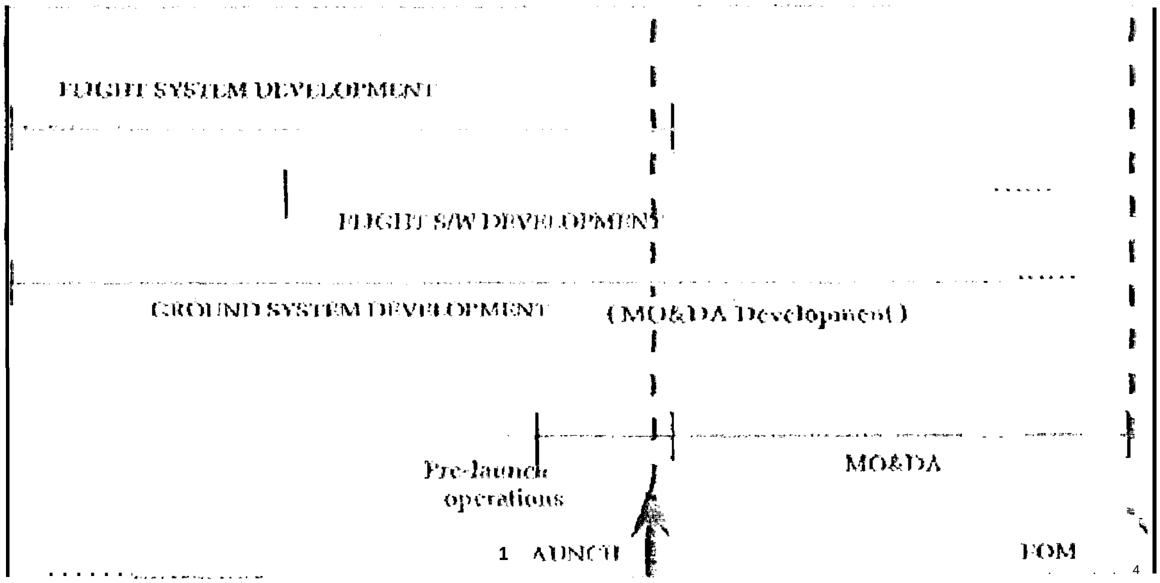

Figure 3 -- Separate Line Items

At the minimum, the MO&DA line item should be split into development and operations. For example, as with Voyager, there are opportunities for development which are not known up front, or even at launch. Continuing the MO&DA development line provides visibility for both long-term development options and uncertainties.

(9) Now it is time to return to the issue of funding. We must allocate a higher percentage of MO&DA funds to continuous improvement plus advanced definition and development in MO&DA tools and systems to address support for future missions. A coordinated program to ensure the development, demonstration, and application of advanced technology in the operation of NASA's science mission would be a significant element in a permanent process for continuous improvement of Mission Operations enabling reduced cost. A program of focused deliveries and technology developments would probably provide the best avenue for continuous improvement plus the insertion of new technology.

Specific Tools and Activities

As a result of these efforts several specific task were initiated to address some of the gaps identified in these studies. These tasks included:

- Develop and maintain MO&DA Cost models to support (1) pre-projects and phase A, the early definition phases, and (2) phase B and phases C/D, the late definition and development phases. Besides modeling tools this effort will produce a standard work breakdown structure
- Formalize the "concurrent engineering" aspects of the mission development life cycle.
- Identify new ground system concepts with potential for cost reduction.
- Formalize the process of identifying, estimating and submitting extended mission options.
- Define a uniform MO&DA contingency management policy.

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If you have comments, questions, or would like to discuss the findings, conclusions and actions, the author may be reached at.

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